

**POLYMERIC MATERIAL WITH VOIDS THAT COMPRESS TO ALLOW THE
POLYMERIC MATERIAL TO ABSORB APPLIED FORCE AND DECREASE
REACTION FORCE TO ONE OR MORE SENSOR FIBERS**

CROSS-REFERENCE TO RELATED APPLICATION

5 This application contains subject matter which is related to the subject matter of the following application, which is assigned to the same assignee as this application. The below-listed application is hereby incorporated herein by reference in its entirety:

**“INTRODUCING VOIDS INTO POLYMERIC MATERIAL FOR
BUFFERING ONE OR MORE STRESS SENSITIVE COMPONENTS
10 FROM ONE OR MORE STRESSES,”** by Carlson, et al., co-filed herewith.

TECHNICAL FIELD

The invention relates generally to sensor fibers and more particularly to buffering sensor fibers.

BACKGROUND

15 Polymeric materials in one example are used for buffering sensor fibers. For example, the polymeric material coats the sensor fiber for protection of the sensor fiber. In one example, the polymeric material comprises a potting compound and the sensor fiber comprises an optical fiber. The potting compound comprises a buffer layer for the optical fiber. The optical fiber is wound about a spool in a winding pattern to form a fiber optic coil.
20 A fiber optic gyroscope in one example employs the fiber optic coil to sense a rate of rotation. The fiber optic coil comprises a plurality of windings along the length of the spool and one or more layers of windings. As the optical fiber is wound about the spool, the potting material is applied to the outer surface of the optical fiber. For example, a syringe

and brush applicator coats the fiber optic coil with the potting material. The potting material promotes precision in the winding pattern of the fiber optic coil.

The potting compound in one example fills a space between each of the windings and the layers of windings. For example, the potting compound acts a buffer layer between each of the windings and the layers of windings. Upon expansion of the fiber optic coil, the fiber optic coil applies a force on the potting compound. The potting compound has a high bulk modulus. Thus, in response to the applied force the potting compound applies a reaction force on the fiber optic coil. The reaction force applies a pressure, stress, and/or strain on the fiber optic coil. As one shortcoming, the applied pressure, stress, and/or strain on the fiber optic coil may promote a decrease in performance of the fiber optic coil. For example, the rotation measurement of the fiber optic coil for the fiber optic gyroscope may experience a greater bias error due to the applied pressure, stress, and/or strain.

Thus, a need exists for a polymeric material that absorbs a larger portion of an applied force from a sensor fiber. A further need exists for a polymeric material that promotes a decrease in reaction pressure, stress, and/or strain applied to a sensor fiber.

SUMMARY

The invention in one embodiment encompasses an apparatus. The apparatus in one example comprises a polymeric material that abuts one or more sensor fibers. The polymeric material comprises a plurality of voids. Upon an introduction of an applied force to a portion of the polymeric material, one or more of the plurality of voids compress to allow the portion of the polymeric material to absorb a portion of the applied force and promote a decrease of a reaction force from the portion of the polymeric material to one or more of the one or more sensor fibers.

Another embodiment of the invention encompasses an apparatus. The apparatus, in one example comprises a fiber optic sensing coil of a fiber optic gyroscope. One or more

portions of the fiber optic sensing coil are coated with a potting material that comprises a plurality of voids. Upon contact with the fiber optic sensing coil, the plurality of voids compress to promote a decrease in a strain on the fiber optic sensing coil. The decrease in the strain on the fiber optic sensing coil promotes a decrease in a bias error of the fiber optic
5 sensing coil.

Yet another embodiment of the invention encompasses a method. One or more sensor fibers in abutment with a polymeric material are buffered through employment of a portion of the polymer material that comprises a plurality of voids to absorb a portion of an applied force. Compression of one or more of the plurality of voids is accommodated in response to
10 the applied force to promote a decrease in a reaction force from the polymeric material to one or more of the one or more sensor fibers.

DESCRIPTION OF THE DRAWINGS

Features of exemplary implementations of the invention will become apparent from the description, the claims, and the accompanying drawings in which:

15 FIG. 1 is a sectional representation of one exemplary implementation of an apparatus that comprises one or more spools and one or more sensor fiber coils.

FIG. 2 is a sectional representation of the sensor fiber coil directed along line 2-2 of FIG. 1.

DETAILED DESCRIPTION

20 Turning to FIG. 1, an apparatus 100 in one example comprises a plurality of components such as hardware components. A number of such components can be combined or divided in one example of the apparatus 100. The apparatus 100 in one example comprises any (e.g., horizontal, oblique, or vertical) orientation, with the description and

figures herein illustrating one exemplary orientation of the apparatus 100, for explanatory purposes.

The apparatus 100 in one example comprises one or more spools 102 and one or more sensor fiber coils 104. For example, the apparatus 100 comprises a sensing component of a fiber optic gyroscope. The fiber optic gyroscope in one example comprises a light source, a beam splitter, the sensor fiber coil 104, and processing electronics. Light from the light source is split by the beam splitter into two counter-propagating waves traveling through the sensor fiber coil 104. The processing electronics measure a phase relationship between the two counter-propagating beams of light that emerge from opposite ends of the sensor fiber coil 104. The difference between the phase shifts experienced by the two beams is proportional to the rate of rotation of the fiber optic gyroscope, due to the Sagnac effect, as will be understood by those skilled in the art.

The spool 102 provides a support structure for the sensor fiber coil 104. The spool 102 comprises a hub 106 and a flange 108. The hub 106 in one example comprises a solid or hollow cylindrical member. The flange 108 comprises a rim at an end of the hub 106. The diameter of the flange 108 is larger than the diameter of the hub 106. The hub 106 and the flange 108 in one example comprise a rigid material such as steel. In a further example, the hub 106 and the flange 108 comprise a unitary construction and/or integral formation.

In one example, the hub 106 and the flange 108 directly support the sensor fiber coil 104. In another example, buffer layers 110 and 112 support the sensor fiber coil 104. The buffer layer 110 is located on the hub 106 and the buffer layer 112 is located on the flange 108. For example, the buffer layer 110 is located between the hub 106 and the sensor fiber coil 104 and the buffer layer 112 is located between the flange 108 and the sensor fiber coil 104. The buffer layers 110 and 112 comprise compressible and/or resilient layers. For example, the buffer layers 110 and 112 comprise a polymeric material, such as a potting

compound. The buffer layer 110 in one example comprises a coating on the hub 106. The buffer layer 112 in one example comprises a coating on the flange 108. The buffer layers 110 and 112 serve to promote a decrease in strain and strain gradients in the sensor fiber coil 104.

The buffer layers 110 and 112 in one example are applied to the spool 102 before the sensor fiber coil 104 is wound about the hub 106. For example, the buffer layers 110 and 112 are applied to the spool 102 in a liquid or paste form. Next, the buffer layers 110 and 112 are preserved and/or finished. For example, the buffer layers 110 and 112 are cured. In another example, the buffer layers 110 and 112 are pre-formed and then applied to the spool 102.

Turning to FIGS. 1 and 2, the sensor fiber coil 104 in one example comprises one or more sensor fibers 202 and a polymeric material 204. For example, the one or more sensor fibers 202 comprise one or more stress sensitive components and the polymeric material 204 buffers the stress sensitive components from one or more stresses. The sensor fiber 202 in one example comprises an optical path or waveguide for propagation of light. The sensor fiber 202 comprises a relatively high thermal expansion coefficient. During thermal increases, the sensor fiber 202 expands. During thermal decreases, the sensor fiber 202 contracts. The expansions and/or contractions exert circumferential strain on a glass core of the sensor fiber 202.

The sensor fiber 202 is wound about the hub 106, for example, in one or more layers. Each layer in one example is located at a respective approximate distance outward from the hub 106. For example, a first layer is wound directly on the hub 106. In another example, the first layer is wound onto the buffer layer 110 atop the hub 106. Subsequent layers are wound about the first layer. The sensor fiber coil 104 in one example comprises a quadrupole-winding pattern. In another example, the sensor fiber coil 104 comprises a dipole-winding pattern, as will be understood by those skilled in the art.

The polymeric material 204 in one example comprises a carbon filled silicon material or a silver filled silicon material. For example, the polymeric material 204 comprises a potting compound. The polymeric material 204 serves to bond together turns of the sensor fiber coil 104. As the sensor fiber 202 is wound about the spool 102, the polymeric material 204 is applied to the outer surface of the sensor fiber 202. For example, a syringe and brush applicator coats the sensor fiber 202 with the polymeric material 204. The polymeric material 204 serves to hold the sensor fiber coil 104 as a wound unit about the spool 102. For example, the polymeric material 204 is located between adjacent portions of the sensor fiber 202.

The polymeric material 204 comprises a solid material 206 and a plurality of voids 208. The voids 208 fill a controlled volume percentage of the polymeric material 204. The voids 208 in one example fill up to twenty-five percent of the total volume of the polymeric material 204. In a further example, the voids 208 fill ten percent of the total volume of the polymeric material 204. An introduction of the voids 208 into the polymeric material 204 reduces the density of the polymeric material 204. The introduction of the voids 208 into the polymeric material 204 also promotes a decrease in a bulk modulus of the polymeric material 204. In a further example, the introduction of the voids 208 into the polymeric material 204 promotes the decrease in the bulk modulus without substantially altering a Young's modulus of the polymeric material 204. The bulk modulus ("B") of the polymeric material 204 is defined by the following exemplary equation:

$$B = V(dP / dV)$$

Where "V" represents the volume of the polymeric material 204.

Where "P" represents the external pressure.

The ratio of bulk modulus ("B") to Young's modulus ("E") of the polymeric material

204 is defined by the following exemplary equation:

$$B/E = 1/[3(1 - 2\rho)]$$

Where “ ρ ” represents the Poisson’s ratio.

In one example, the polymeric material 204 with the voids 208 has a lower Poisson's ratio than the solid material 206 without voids. Since the voids 208 do not substantially alter the Young’s modulus of the solid material 206, then it follows that a decrease in the Poisson's ratio results in a decrease in the bulk modulus of the polymeric material 204. Thus, in one example a decrease in the Poisson's ratio from 0.499 to 0.490 results in a decrease in the ratio of bulk modulus to Young’s modulus by a factor of ten.

The bulk modulus of a solid polymer in one example is substantially greater than the bulk modulus of a gas. For example, the bulk modulus of the solid polymer may be ten thousand times greater than the bulk modulus of the gas. Also, thermal pressure coefficients of the solid polymer in one example are substantially greater than the thermal pressure coefficients of the gas. For example, the thermal pressure coefficients of the solid polymer may be three thousand times greater than the thermal pressure coefficients of the gas. Thus, a controlled amount of the voids 208 in the polymeric material 204 decreases the bulk modulus and thermal pressure coefficient of the polymeric material 204.

In one example, the voids 208 comprise one or more gas (e.g., air) bubbles in the solid material 206. In another example, the voids 208 comprise a structure that preserves a space in the solid material 206. In a further example, the voids 208 comprise hollow elastomeric bubbles, for example, hollow elastomeric microspheres. The hollow elastomeric microspheres comprise microballons with thin walls that encapsulate a gas to allow for easy compression. For example, the walls of the hollow elastomeric microspheres are strong enough to avoid breakage under pressure, but thin enough to easily compress. In a further example, once cured in the solid material 206, the hollow elastomeric microspheres comprise substantially similar compressibility characteristics as gas bubbles. The voids 208 in one

example are added to a resin of the solid material 206 in a substantially uniform distribution. For example, the hollow elastomeric microspheres are stirred into the resin of the solid material 206.

A coupling agent in one example is used to increase an adhesion between the hollow
5 elastomeric microspheres and the solid material 206. The coupling agent in one example comprises organofunctional reactive silane. The coupling agent also promotes a decrease in a rate of settling of the hollow elastomeric microspheres in the solid material 206. For example, the coupling agent maintains the substantially uniform distribution of the hollow elastomeric microspheres in the solid material 206. The solid material 206 and the voids 208
10 are cured to maintain the substantially uniform distribution of the voids 208 within the solid material 206.

The voids 208 comprise a diameter that is smaller than a distance of separation between adjacent portions 210 and 212 of the sensor fiber 202. For example, one or more of the voids 208 fit between the adjacent portions 210 and 212 of the sensor fiber 202. The
15 voids 208 in one example comprise the hollow elastomeric microspheres with a diameter that is small enough to fit between the adjacent portions 210 and 212 of the sensor fiber 202. For example, in one implementation the diameter of the voids 208 of the sensor fiber coil 104 for the fiber optic gyroscope is less than fifty micrometers. In a further example, the diameter of the hollow elastomeric microspheres is twelve micrometers.

20 In one example, the voids 208 reserve space in the solid material 206 to increase a compressibility of the polymeric material 204. For example, the voids 208 promote an increase in an amount of an applied force the polymeric material 204 can absorb. Upon an introduction of the applied force to a portion of the polymeric material 204, one or more of the voids 208 compress to allow the portion of the polymeric material 204 to absorb a portion
25 of the applied force. For example, the applied force pushes a portion of the solid material

206 into the space previously reserved by the voids 208. The voids 208 also promote a decrease of a reaction force generated by the portion of the polymeric material 204 in response to the applied force. Since the voids 208 allow the polymeric material 204 to absorb a larger portion of the applied force, the magnitude of the reaction force from the polymeric
5 material 204 is decreased.

In one example, as the temperature of the sensor fiber coil 104 increases, one or more of the sensor fiber 202 and the polymeric material 204 expand. Due to the expansion, the sensor fiber 202 exerts a thermal pressure on the polymeric material 204 and the polymeric material 204 exerts a thermal pressure on the sensor fiber 202. The voids 208 compress to
10 promote a decrease in the thermal pressure that the polymeric material 204 exerts on the sensor fiber 202. For example, when the polymeric material 204 expands, the solid material 206 expands into the space previously reserved by the voids 208 rather than adding to the thermal pressure that the polymeric material 204 exerts on the sensor fiber 202.

Contact between the sensor fiber 202 and the polymeric material 204 in one example
15 introduces a stress, strain, stress gradient, and/or strain gradient in the sensor fiber 202. The stress and/or strain may degrade the performance of the sensor fiber 202. For example, the stress and/or strain may reduce the polarization maintaining properties of the sensor fiber 202. The voids 208 compress to promote a decrease in the magnitude of any stress, strain, stress gradient, and/or strain gradient applied by the polymeric material 204 to the sensor
20 fiber 202.

In one example, the polymeric material 204 encapsulates the sensor fiber 202 for the fiber optic gyroscope. The compression of the voids 208 promotes a decrease in measurement bias errors of the fiber optic gyroscope. For example, the decrease in the magnitude of the stress, strain, stress gradient, and/or strain gradient applied by the polymeric
25 material 204 to the sensor fiber 202 promotes an increase in accuracy and a decrease in the

rotation sensing bias error of the fiber optic gyroscope. The compression of the voids 208 promotes a decrease in a Shupe coefficient of the fiber optic gyroscope.

In another example, the polymeric material 204 encapsulates one or more electrical components, for example, electronic and optical sensor equipment. A power supply in one example employs the polymeric material 204 as a potting compound for the electrical components. The voids 208 of the polymeric material 204 in one example compress under pressure to avoid structural failure to one of the electrical components such as a glass-bodied diode. The reduced bulk modulus and increased compressibility of the polymeric material 204 due to the voids 208 are advantages for electrical component encapsulation. For example, the reduced bulk modulus and increased compressibility of the polymeric material 204 promotes a decrease in likelihood that contact with the polymeric material 204 will damage the electrical components. In one example, the polymeric material 204 encapsulates an optical coupler. The reduced bulk modulus of the polymeric material 204 allows for complete coverage of the optical coupler with the polymeric material 204. An acoustic sensor in one example employs the polymeric material 204 to buffer an optical fiber from a sensing component. For example, the reduced bulk modulus of the polymeric material 204 promotes a decrease in an amount of acoustic noise that reaches the optical fiber.

In yet another example, the polymeric material 204 with the plurality of voids 208 is used to create the buffer layers 110 and 112. For example, the buffer layers 110 and 112 comprise the plurality of voids 208. As a further example, the polymeric material 204 of the sensor fiber coil 104 and the buffer layers 110 and 112 are made from substantially the same material. Thus, the reduced bulk modulus and increased compressibility characteristics of the polymeric material 204, described herein, are substantially similar to the bulk modulus and compressibility characteristics of the buffer layers 110 and 112 that comprise the plurality of

voids 208. The plurality of voids 208 in the buffer layers 110 and 112 promote a decrease in contact forces between the spool 102 and the sensor fiber coil 104.

The steps or operations described herein are just exemplary. There may be many variations to these steps or operations without departing from the spirit of the invention. For
5 instance, the steps may be performed in a differing order, or steps may be added, deleted, or modified.

Although exemplary implementations of the invention have been depicted and described in detail herein, it will be apparent to those skilled in the relevant art that various modifications, additions, substitutions, and the like can be made without departing from the
10 spirit of the invention and these are therefore considered to be within the scope of the invention as defined in the following claims.